Chapter 9
GPS Real Time Kinematic Topographic Survey Procedures

9-1. Purpose and Scope

This chapter provides guidance on the use of GPS Real-Time Kinematic (RTK) positioning methods for performing topographic surveys of terrain, facilities, and infrastructure. RTK and total station methods provide identical output coordinate data. The only difference is that a total station must perform a visual observation from a reference station to some remote point to obtain a coordinate, whereas an RTK system derives the coordinates of the remote point by reducing carrier phase data over a GPS baseline between the reference (base) station and the remote point. The RTK base/reference point need not be visible and may be miles distant from the project site. Both systems employ similar (or identical) data collector devices, feature coding, attribution of features, stakeout methods, COGO functions, etc. Some data collectors (e.g., the Trimble TSC) can be connected to either a total station or a GPS receiver for RTK operation. Thus, this chapter will cover only those RTK survey functions that are unique to real-time GPS surveying--the standard data collector and COGO functions covered in previous chapters will not be repeated. Only detailed site plan mapping applications with RTK will be covered. EM 1110-1-1003 (*NAVSTAR GPS Surveying*) should be consulted for small-scale "mapping grade" GPS applications and procedures, such as use of meter-level positioning systems for GIS mapping. Some of the material in this chapter is taken from applicable sections on RTK surveying in EM 1110-1-1003. This GPS manual should be consulted for the basic theory and principles of GPS (and RTK) surveying. An example of an RTK topographic survey of a Corps project is shown in Appendix D of EM 1110-1-1003--"*Application: Dredge Material Disposal Area RTK Cross-Sections-(Jacksonville District).*" Additional examples of RTK surveys are provided in appendices to this manual--see Appendix J: "*Application: Topographic Survey for Proposed US Army Reserve Center Belaire, Belmont County, Ohio (Louisville District).*"

Figure 9-1. Real-Time kinematic survey of Corps lock and dam project--hand-held fixed height antenna pole

9-2. RTK Field Techniques

Unlike GPS static survey methods used for precise control surveys (Figure 9-2 below), RTK methods provide real-time positioning results; thus, it can be used like a total station for real-time construction stakeout, setting project control, or topographic mapping. To obtain real-time coordinates at a remote ("rover") point, a communication link (radio, cell phone, or satellite) is required between the reference base station and the roving receiver. The remote/rover receiver is mounted on a range pole, similar to a prism pole for a total station. The operator at the remote receiver performs all survey and data collection functions at that point (the reference station is unattended). Thus, one-man survey crew operation is feasible if the reference station can be placed in a secure location. RTK surveying requires both the reference and remote receivers simultaneously recording observations. Periodic losses of the communication link can also be tolerated and/or corrected for in post-processing (e.g., PPRTK solutions). Unlike total station shot methods, the RTK rover receiver can be continuously moving--used for marking linear continuous features. RTK surveys require dual-frequency (L1/L2) GPS observations.

Figure 9-2. Static or Fast-Static survey techniques. Rover is set on a tripod accurately centered over a control point or feature such as a photo target. 5 minutes to 2 hours of static data may be collected whereas an RTK solution may have only a few seconds using a hand-held antenna pole.

a. Ambiguity resolution. Carrier phase integer ambiguity resolution is required for successful RTK baseline formulations. A fixed solution is essential for RTK surveys--float solutions over short distances are not accurate enough for engineering surveys. RTK surveys can be initialized at a known point. However, most systems employ "on-the-fly" (OTF) initialization technology, where the remote receiver can initialize and resolve integers without a period of static initialization. With OTF capability, if loss of satellite lock occurs, initialization can occur while in motion. OTF integers can usually be resolved at the rover within 10-30 seconds, depending on the distance from the reference station. This initialization is automatically performed by the survey controller device. OTF makes use of the L2 frequency in resolving the integer ambiguity. A minimum of 5 satellites are required for OTF initialization, and after initialization, at least 4 satellites must be tracked. After the integers are resolved, only the L1 C/A is used to compute the positions. If no OTF capability is available, then initialization should be made at a known point and 4 satellites must be kept in view at all times and loss of satellite lock would require reinitialization. For QA purposes, OTF initialization may be made at a known location (control monument).

b. Survey procedure. Like the total station, RTK surveys are performed in a radial manner about a base station--see Figure 9-3 below. One of the GPS receivers is set over a known point (base station) and the other is placed on a moving or roving platform. The survey controller will determine the amount of time required to lock in over each remote point. If the survey is performed in real-time, a data link and a processor (external or internal) are needed. The data link is used to transfer the raw data from the reference station to the remote. If the radio link is lost, then post-processing techniques (PPRTK) are available to compute the survey, such as Trimble's "Infill" option, provided the raw GPS observations are collected during the survey. Since most unlicensed radio frequencies have limited range (one mile ±), booster or repeater stations may be used if the job site is large. Alternatively, multiple base stations may be set up to extend coverage. Networked "virtual reference stations" are also available in some areas, allowing extended RTK coverage using cell phone modems in addition to adjusted solutions from the multiple bases.

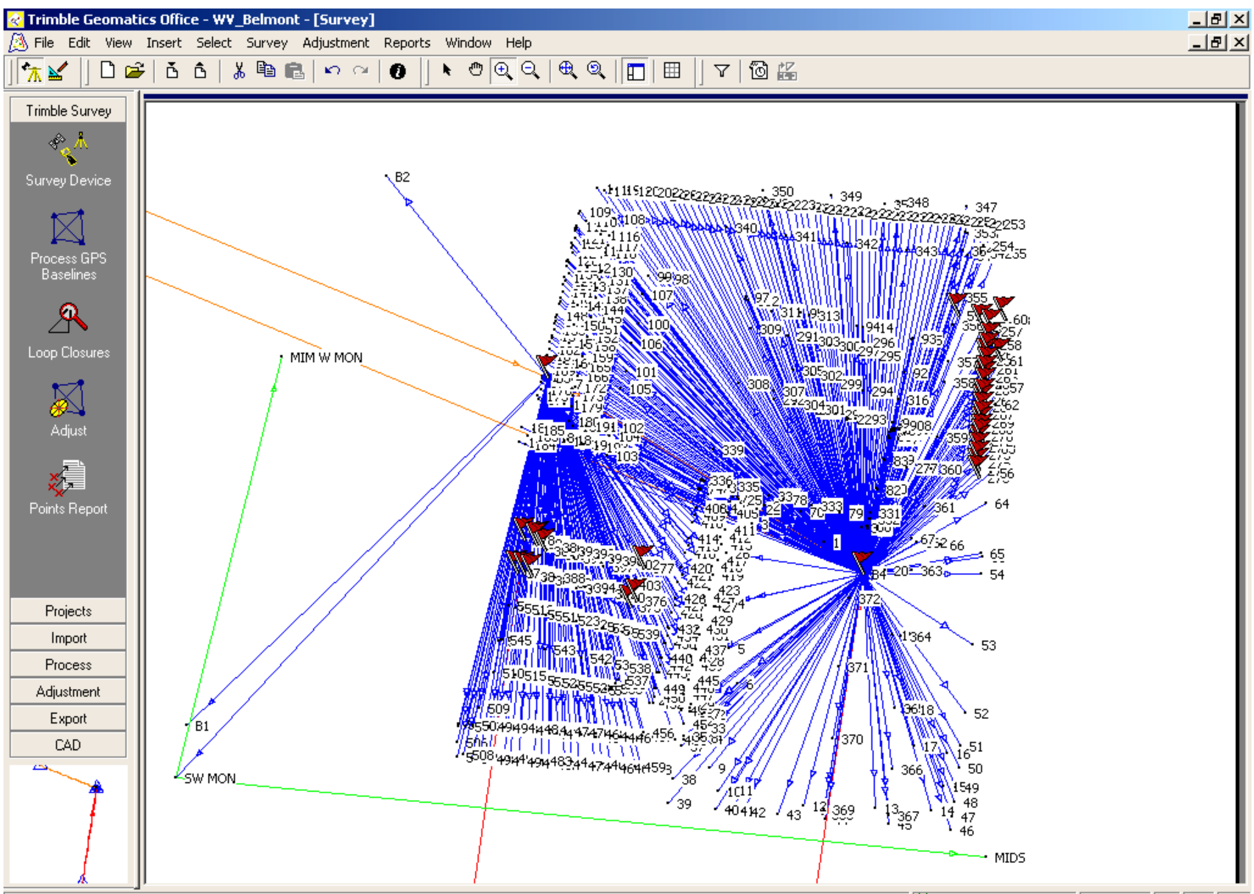

Figure 9-3. RTK Radial Survey Method--Proposed USARC, Belmont Co., Ohio (Louisville District)

c. Accuracy of RTK surveys. RTK surveys are accurate to within 3-10 cm (in 3D) when the distance from the reference to the rover does not exceed 10 k. Expected 3D accuracies over short distances (less than one mile from reference base) are typically around the 0.1 ft range; provided that a good site calibration has been performed--see section 9-4.

d. General data collection operation. The following functions are required to perform an RTK survey.

- Set up horizontal and vertical projection grid
- Establish coordinates of reference point
- Configure reference and rover hardware
- Establish radio link between reference and rover
- Collect coordinate data at fixed monuments and benchmarks around survey site
- Perform site calibration (or localization) with appropriate geoid model (see section 9-4)
- Perform topographic or stakeout measurements--store points with descriptors and attributes

Some of the above items will be covered in the following sections. They are covered in greater detail in the GPS receiver operation or reference manuals (e.g., Trimble 2001), or in training courses developed for specific receivers and/or RTK data collectors (e.g., "*Survey Pro for Window CE--GPS RTK Training Guide*").

e. Receiver set up. Figure 9-4 below depicts the set up configuration for a GPS rover receiver, as set up for RTK surveys. The radio link component must be set for maximum distance--and repeaters added if surveying a large site. Different channels may need to be tested to avoid interference. Once the system is set up and activated, the base station receiver must be initialized with the coordinates (and datum) of the point over which it is set. The rover receiver is then activated and initialized at a known point or by OTF methods.

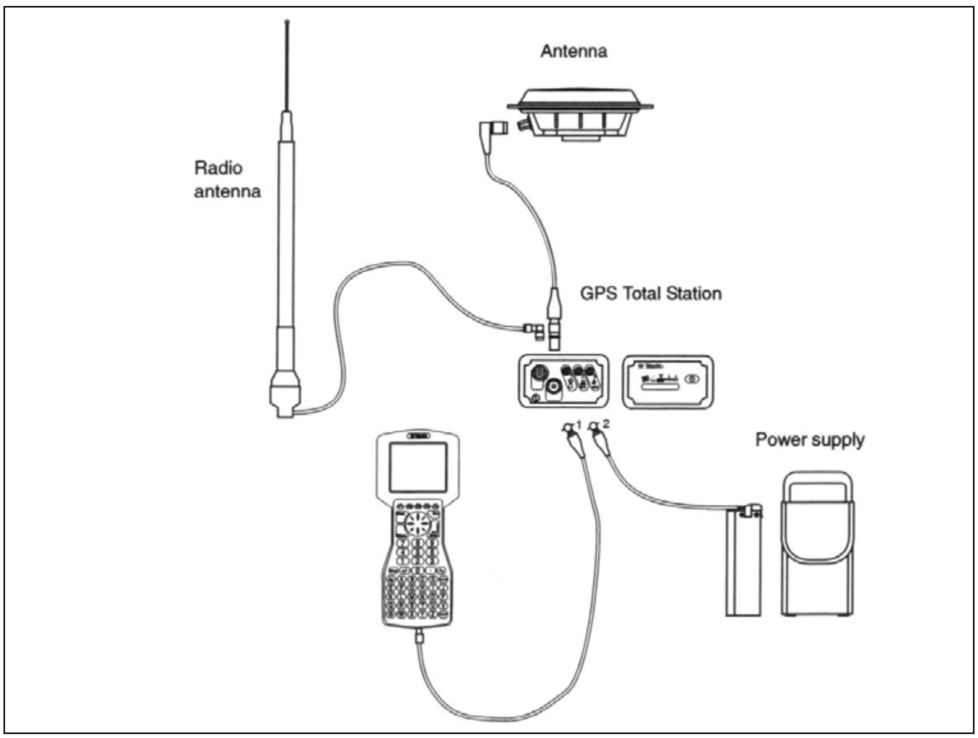

Figure 9-4. Rover GPS receiver setup for RTK surveys--Trimble Navigation LTD

Reference (Base) Station

Remote (Rover) Station

Figure 9-5. Trimble RTK survey system (David Evans & Associates, Inc)

9-3. Standard RTK Observing Procedures

The following guidance is excerpted from Woolpert, Inc. published instructions to their field survey personnel, many of whom work on Corps projects. These instructional procedures are representative of quality control and quality assurance checklists that should be developed and used by field personnel.

RTK Survey Standard Operating Procedures (Woolpert, Inc.)

BASE STATION SETUPS:

- Place base station in clear, open, location--360 deg clear sky >10 degs
- Use Ground-plane (GP) on all base station setups
- Completely fill out base station log sheet
- RECORD BASE STATION DATA – use RTK-Infill on base station receivers
- When working from known/fixed coordinates, double-check to ensure that coordinates have been entered correctly
- Ensure that both primary and backup batteries are fully charged
- Base station equipment needs a listing of licensed radio freq.

EQUIPMENT MANAGEMENT:

- When equipment is received from a different office or was last used at a distant location from current, reset/reboot receiver (See operation manual for details)
- Be aware of battery power capacity before beginning survey – CHARGE BATTERIES the night before!
- Check and adjust plum on all FH-tripods and rover staffs prior to the start of every survey
- Keep cables and hardware clean and in operation
- Always carry a spare antenna cable.
- Keep all equipment and cables in protective cases

ROVERS PROCEDURES:

- Initialize the equipment in clear, open location
- Check into a minimum of 2 control points as frequently as possible throughout the duration of survey
- Set PDOP mask @ 5.0
- Set SV Elevation mask @: 15 degrees

SITE CALIBRATION:

- A minimum of **four (4)** 3D local grid coordinates and **four (4)** WGS-84 coordinates must be used to complete a site calibration
- A survey consisting of conventional measurements only **do not** require a site calibration
- Extremely important! Do not conduct survey outside the polygon you create from the calibration
- Points in Site Calibration NTE a residual tolerance of:
  Stake-out & Control: 0.10 sft
  Topo & Reconnaissance: 0.15 sft

SETTING UP SURVEY CONTROLLER PROJECT

1. Prior to field work, perform GPS Skyplot with most recent ephemeris file available
2. From main menu, select *Files*
3. Select New *Job*
4. Enter the job name in the *Name* field
5. In the Select coordinate system field, select a coordinate system option
► Select from library – uses a list of pre-defined coordinate systems saved on device
► Key in parameters – allows user to import the projection and transformation parameters
► Scale factor only – uses a coordinate system based on scale factor only, enter scale factor
► Copy from other job – allows user to use coordinate system previous defined in other project
► No projection/No datum – selects a coordinate system with an undefined projection and datum
6. Link background files (i.e.: *.dxf) by tapping *Background File* button
7. Link control point coordinate files (i.e.: *.csv) by tapping *Control File* button
8. Open the job by highlighting the job's name and tapping Enter

SITE CALIBRATION PROCEDURES

A site calibration combines GPS measurements and conventional measurements with local coordinate system control points!!
1. Check or enter the calibration tolerances
2. Use the RTK to observe and measure a minimum of 4 control points
A. GPS control points that have local grid coordinates
B. Name the GPS point differently (but similar) to the local grid point names i.e.: Grid Point Name = 100 _ WGS-84 Point Name = 100_GPS
3. Perform site calibration operation:
A. From main menu, choose *Survey*
B. Choose *Site Calibration*
C. Tap **Add** button
D. In the Grid Point Name box, enter a local grid point name _ In the GPS Point Name box, enter the GPS point name associated to the local point name
E. Choose the type of calibration to be used (Horz & Vert, Horz, or Vert)
F. The results screen appears showing residuals once 3 horizontal points or 4 vertical points are entered
G. Tap **ESC** to return to the calibration screen
H. Enter all control observed following steps **C.** thru **E.**
I. When finished entering all control points, tap **Apply** to store the calibration, or recalculate if residuals are not acceptable
J. If *Auto calibrate* is checked, Survey Controller will automatically continue to calculate calibration as more control points are observed

TRAVERSE & CONTROL SURVEY PROCEDURES

All new control points set for the purpose of traverse, base station or other control needs are required to be observed at least twice during different satellite constellations (at least one hour time separation between observations)
- Use of multiple base stations are required for redundancy, data postprocessing, and provides the possibility to perform a least-squares adjustment to data
- It is recommended that static GPS procedures be employed when establishing:

1. Prior to field work, perform GPS Skyplot with most recent ephemeris file available
2. Set base station location--either set new point or use existing control
3. Assemble base station equipment
4. Connect ACU, TSC1 or TSCe data collectors to setup
5. Power up base system
6. Start base station survey in Survey Controller - Survey Style: RTK INFILL
7. Check setup for faulty operation of receiver, radio and cables
8. Disconnect data collector from setup
9. Assemble rover equipment with data collector attached
10. Power up rover system
11. Check setup for faulty operation of receiver, radio and cables
12. Proceed to and check into control point(s) previously established
13. Begin observations of points set as traverse points using CONTROL POINT survey – 3 minute observation (180 sec)
14. If survey spans more than 2 hours in length, a random check should be made on nearby control
15. End the survey by checking into control point(s) previously established
16. Complete second pass through all control and all traverse points, repeating steps 11 thru 14 at every point during a different satellite constellation
17. Connect data collector to base station setup and End Survey

TOPOGRAPHIC SURVEY PROCEDURES

All new control points are required to be observed at least twice during different satellite constellations (at least one hour time separation between observations)
1. Begin topographic observations while observing proper topo-survey techniques and feature coding – each point a minimum of a 5 second observation (5 sec)
2. If survey spans more than 2 hours in length, a random check should be made on nearby control.

9-4. Site Calibration

A site calibration (also called a localization) must be performed before conducting a RTK survey. This is because the local georeferenced coordinate system is not planer with the GPS ellipsoid system. For example, a given project site may be on local NAD 83 horizontal coordinates and have a NGVD 29 vertical datum; RTK satellite observations are on the WGS 84 ellipsoid. A site calibration "best fits" horizontal and vertical variances (undulations) such that observed GPS positions on the ellipsoid are corrected to best fit the local datum at points within the site. Calibration of vertical geoid undulations is especially critical when RTK techniques are used for topographic ground shots or vertical stakeout. A calibration is needed in real-time kinematic surveying in order to relate GPS positions that are measured in terms of WGS-84 to local grid coordinate projections, such as SPCS, UTM, or a local station-offset-elevation system. In addition, a vertical calibration is needed to adjust the observed GPS ellipsoid elevations to a local vertical datum, and account for undulations in the local geoid over the project area. A calibration should be used on a project whenever new points are to be established. A calibration is based on a set of points that have 3D coordinates in both WGS-84 and the local grid coordinate projection system. The quality of the calibration will be affected by the accuracy and consistency of the GPS-derived coordinates of the points. Points tied to the NSRS are recommended as the basis of a calibration. The number of points that can be used in a calibration is manufacturer and software dependent. Smaller sized projects may be calibrated with one 3D point. However, for larger sized projects, three or four 3-D points are recommended. Calibration points should be well distributed around the project exterior. Projects may be calibrated by two methods: (1) in the field in the survey data collector or (2) in the network adjustment. The later procedure is recommended for large projects. The calibration computation summary should be examined for reasonable results in the horizontal scale, maximum vertical adjustment inclination, and the maximum horizontal and vertical residuals.

a. Figure 9-6 below illustrates the varied requirements for vertical site calibrations. This figure depicts a typical contour plot of a geoid model--height differences between the geoid relative to the WGS 84 ellipsoid. In the large (8 km x 8 km) Area A, the geoid undulation varies from 0.80 m to 1.27 m--nearly a 50 cm variation. In order to determine accurate orthometric elevations from GPS ellipsoid elevation observations, this variation in the geoid must be accurately accounted for. In addition, the published orthometric elevations at each of the 7 established control benchmarks may not fit exactly with the geoid model--the geoid model may have been approximated from other NSRS points. Therefore, GPS observations over the 7 established control network points must be adjusted to further refine the geoid model so that subsequent GPS observations to any point in the project area can be "best-fitted" to the local vertical datum. Solely relying on a published geoid model is not recommended--connections with existing control should always be observed to refine the model. GPS adjustment software must be able to compensate for both the variations in the geoid model and variations in the established control benchmarks. In order to accomplish this, GPS observations need to be connected between the fixed control benchmarks, as shown in Area A.

b. The small (1 km x 1 km) Area B in Figure 9-6 below is more typical of local RTK topographic survey projects. The geoid model shows a minimal undulation over this area--from 0.72 m to 0.75 m. This 3 cm variation may or may not be significant, depending on the required elevation accuracy of the survey. If this 3 cm geoid variation is not considered significant, then the geoid undulation at the selected reference station could be used over the entire area, and no geoid model correction used. Alternatively, the 2 control benchmarks could be calibrated and the geoid model included in the adjustment. When 2 control benchmarks are available, as shown around Area B, then a GPS check between the benchmarks is recommended. If the geoid model is not used, the geoid correction could be interpolated from the check baseline observation results, holding the 2 control points fixed.

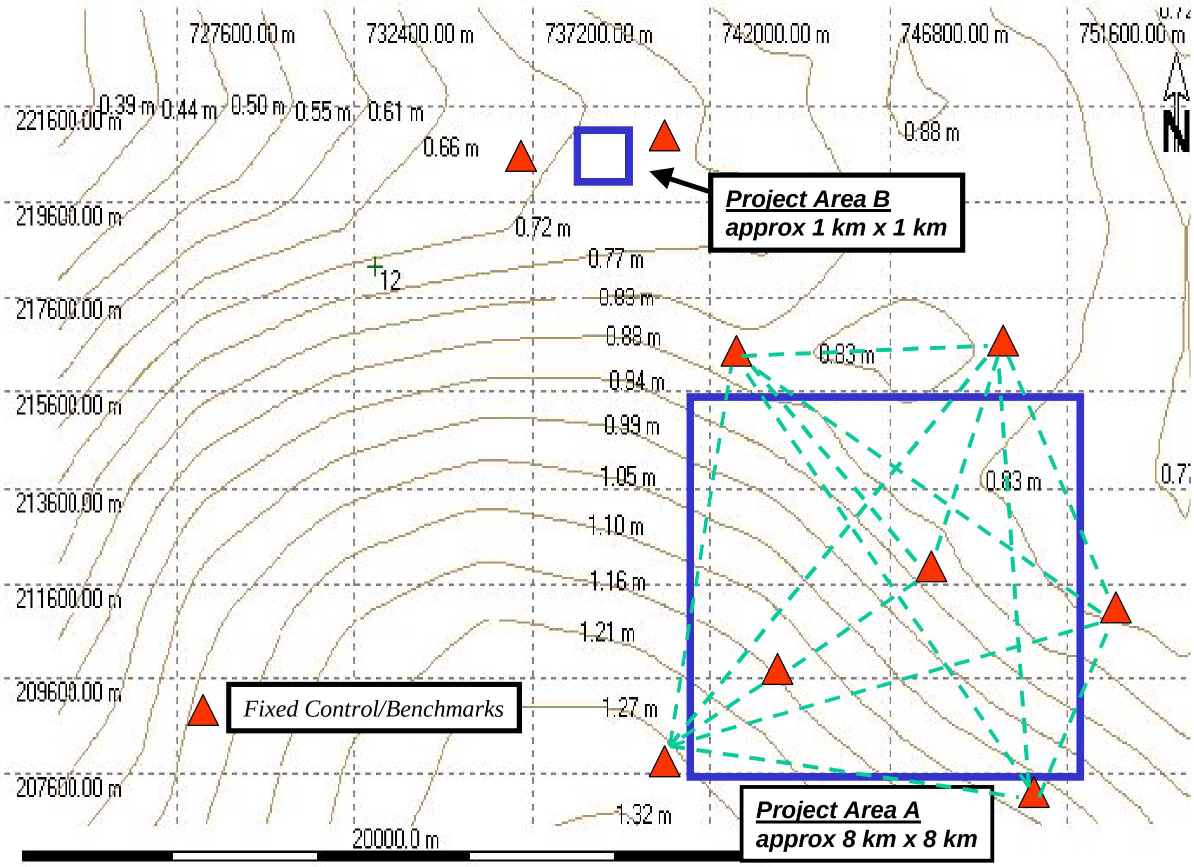

Figure 9-6. Plot of geoid undulation contours over a local survey area (Leica)

c. Figure 9-7 below illustrates vertical calibrations over small local survey areas, which is typical of Corps topographic survey applications. This area contains two fixed benchmarks with local datum elevations. A GPS reference receiver is set up over one benchmark and baseline hubs are staked out relative to this point, using kinematic techniques. The second fixed benchmark is used as a check point. A local geoid model shows estimated geoid heights varying between -11.23 and -11.25 m. Orthometric elevations on the individual baseline hubs are computed by correcting the observed ellipsoidal elevation differences with the local geoid undulation differences. This local geoid elevation difference (- 2 cm) could have been ignored if this error is acceptable to project accuracy requirements. This would, in effect, assume observed ellipsoidal elevation differences are equal to orthometric elevation differences and no geoid model corrections are applied to the observations.

d. In Figure 9-7 below, a check point GPS elevation difference of +12.40 m is observed. The published orthometric elevation difference between these points is +12.42 m. This confirms the geoid model is accurate over this area since the computed geoid undulation difference (ΔN) is - 0.02 m (+12.40 - 12.42). Had a large misclosure existed at the check point, then either the published elevations are inaccurate or the geoid model is inaccurate. A GPS baseline check to a third benchmark would be required, or conventional levels could be run between the two fixed points to resolve the problem.

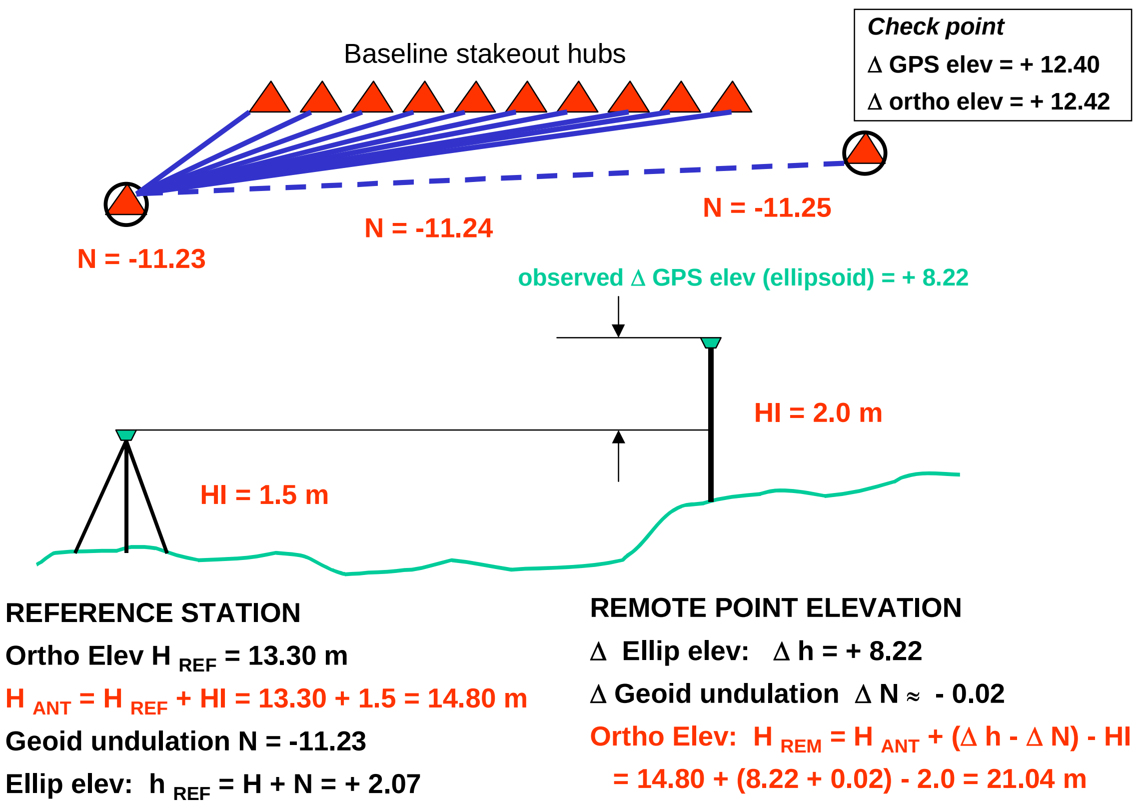

Figure 9-7. Geoid elevation corrections for localized surveys

e. Manual site calibration procedure (Trimble). The Trimble Survey Controller Reference manual (Trimble 2001) outlines the following process for performing a site calibration. This procedure is representative of other RTK systems.

- Key in or upload grid coordinates of all the control/calibration points around the project site
- Set calibration tolerances (acceptable adjustment levels)
- Measure the control/calibration points using the GPS/RTK receiver
- Pair local grid coordinates and WGS 84 coordinates for each control/calibration point
- Activate the site calibration routine on the controller
- Check residual errors v tolerances at each control/calibration point ... recheck points and reject as required
- Apply the final site calibration to the controller

f. Examples of site calibrations can be found in operating or training manuals for RTK equipment, e.g., *Real-Time Surveying Workbook* (Trimble) or *Basic GPS Controller Workshop--Survey Pro for Windows CE* (Tripod Data Systems).

9-5. RTK Survey Field Data Collection Procedures and Checks

Once a site calibration has been performed, field data collection (or stakeout) procedures are straightforward, and are detailed in GPS operation/reference manuals. Figure 9-8 below is a Trimble TSC screen display in the "measure point" mode. This screen shows a topographic shot point (TOPO1001) being measured to. The GPS antenna on the rover is set on a fixed-height pole at 2.00 meters. The bottom of the screen displays the number of satellites being observed (5), the estimated errors in the horizontal (0.009 m) and vertical (0.014 m), and that the fixed solution has an RMS of 7. Optional screen displays will provide HDOP, VDOP, and other satellite related information.

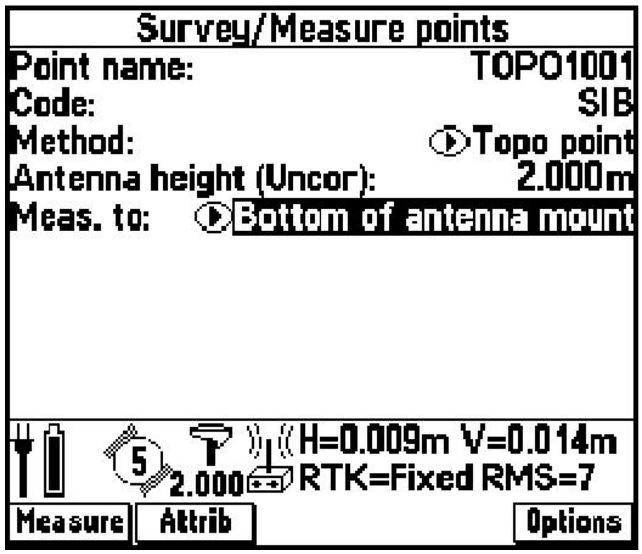

Figure 9-8. Trimble TSC "Measure Points" screen

The USFS and BLM *Standards and Guidelines for Cadastral Surveys* (USFS/BLM 2001) contains guidance for performing RTK surveys that is directly applicable to USACE RTK topographic mapping and construction control surveys. Some of the more significant field procedures recommended by the USFS/BLM are outlined below. These generally reduce down to (1) system checks, (2) measurement procedures, (3) and periodic calibration checks.

a. RTK system check. A RTK system check shall be made prior to any measurements. RTK system checks may also be made at any time during the course of each RTK survey session or at any time the base receiver(s) and rover receiver(s) are set up and initialized per the manufacturer's recommended procedures. This check is a measurement from the RTK base setup to another known project control monument. The resulting observed position is then compared by inverse to the previously observed position for the known point. This inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements--typically within ± 2.5 cm in position and within ± 5 cm in elevation. This RTK system check is designed to check the following system parameters:

- The correct reference base station is occupied.
- The GPS antenna height is correctly measured and entered at the base and rover.
- The receiver antennas are plumb over station at base and rover.
- The base coordinates are in the correct datum and plane projections are correct.

- The reference base stations or the remote stations have not been disturbed.
- The radio-communication link is working.
- The RTK system is initialized correctly.
- RMS values are within manufacturer's limits.

b. RTK measurements. RTK topographic observations are usually made using one or more base stations and one or more rover receivers. RTK measurements shall be made after the system setup check procedures have been completed. Use manufacturer's recommended observation times for the highest level of accuracy when setting mapping or construction control points, for example, 180 seconds of time or when the horizontal (e.g., 2 cm) and vertical (e.g., 5 cm) precision has been met for a kinematic control point. Under optimal conditions a deviation from the manufactures suggested times is appropriate; for example, a point may be observed using 30 seconds of time and 20 epochs of measurement data. However, observation times should be set to account for field conditions, measurement methods (e.g., Trimble "topo point" or "kinematic control point") and the type of measurement checks being performed. Individual features can be quickly observed, as illustrated in Figure 9-9 below.

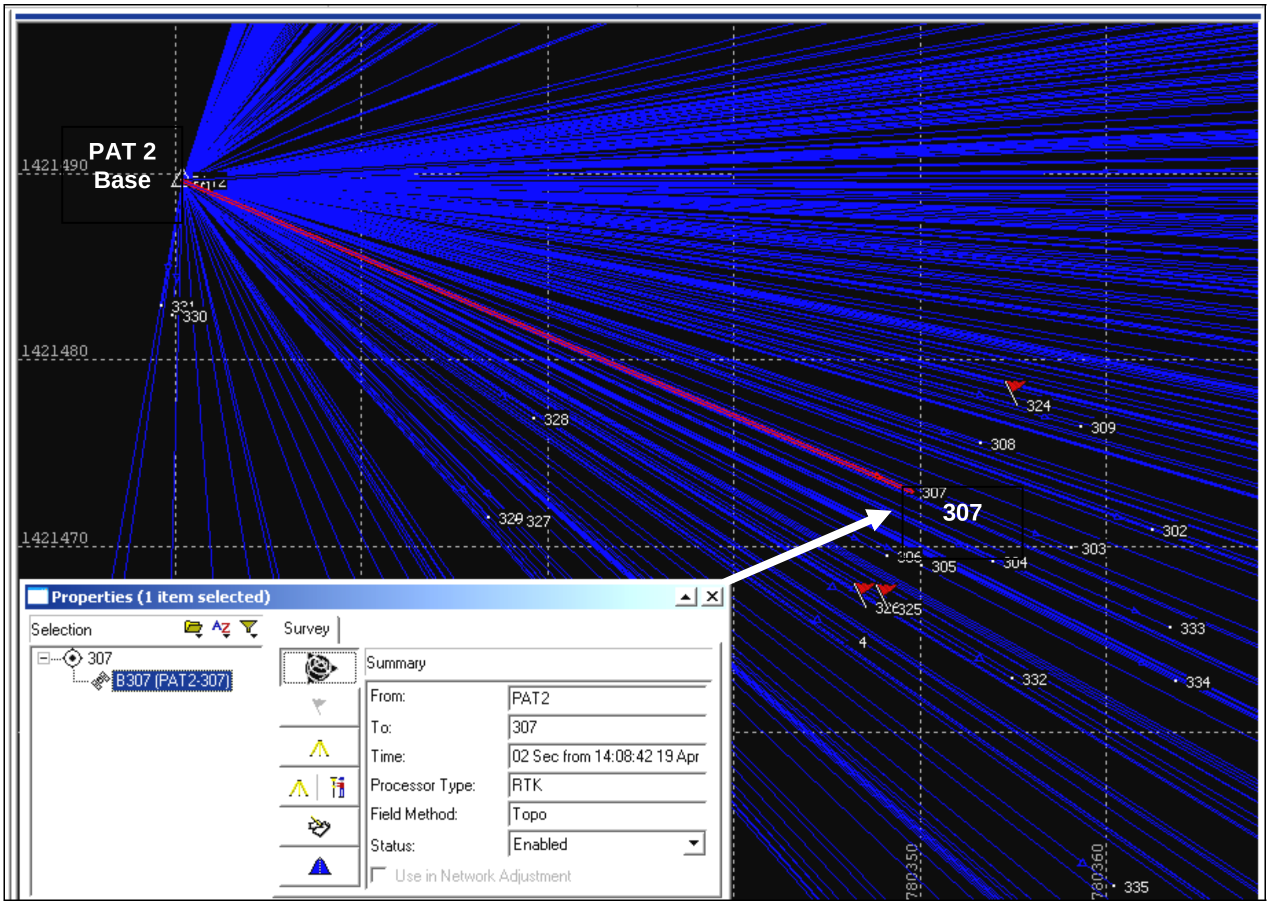

Figure 9-9. Short-term (2-sec) RTK observation on a topographic point--# 307 (Patrick AFB Airfield Surveys--Louisville District)

9-6. Guidance for Setting Construction Control Points Using RTK Techniques

The following general guidance on RTK construction control surveys is taken from the CALTRANS *Surveys Manual*. These procedures will generally meet Third-Order criteria and are applicable to setting control for most construction projects.

RTK survey design*:*

- *The project area shall be "surrounded" and enclosed with RTK control stations. (See the end of this section for the definition of an RTK control station.)*
- *If the RTK control station is used for horizontal control, the RTK control station shall have horizontal coordinates that are on the same datum and epoch as the datum and epoch required for the project.*
- *If the RTK control station is used for vertical control, the RTK control station shall have a height that is on the same datum as the datum required for the project.*
- *All RTK control stations shall be included in a GPS site calibration. (See the end of this section for the definition of a GPS site calibration.)*
- *If the RTK equipment does not support the use of a GPS site calibration, the RTK control stations shall be used for check shots.*
- *For third order RTK surveys, each new station shall be occupied twice. The 2nd occupation of a new station shall use a different base station location. If the new station is being elevated by RTK methods, the 2nd occupation of the new station shall have a minimum of 3 different satellites in the satellite constellation. This is generally achieved by observing the 2nd occupation at a time of day that is either 4 hours before or 4 hours after the time of day of the 1st occupation.*
- *Establish the new stations in areas where obstructions, electromagnetic fields, radio transmissions, and a multipath environment are minimized.*
- *Use the current geoid model when appropriate.*

> *Definition: An RTK control station is a station used to control a survey that utilizes RTK methods. The station shall have either horizontal coordinates, a height, or both. The order of accuracy of the horizontal coordinates and the height shall be at least third order.*
>
> *Definition: A GPS site calibration establishes a relationship between the observed WGS84 coordinates and the known grid coordinates. This relationship is characterized by a translation, rotation, and scale factor for the horizontal coordinates and by an inclined plane for the heights. By applying a GPS site calibration to newly observed stations, local variations in a mapping projection are reduced and more accurate coordinates are produced from the RTK survey.*
>
> *Note: A GPS site calibration can be produced from RTK observations, an "office calibration," or from a combination of both. If the RTK control stations were established by static or fast static GPS techniques, then an office calibration may be used. The procedures for an office calibration are:*

- *Do a minimally constrained adjustment before normalization holding only one WGS84 latitude, longitude, and ellipsoid height fixed.*
- *The epoch of the fixed values shall correspond to the epoch of the final coordinates of the RTK survey.*
- *Associate the results of this minimally constrained adjustment with the final grid coordinates in a site calibration.*

Satellite Geometry*: Satellite geometry affects both the horizontal coordinates and the heights in GPS/RTK surveys. The satellite geometry factors to be considered for RTK surveys are:*

- *Number of common satellites available at the base station and at the rover unit.*
- *Minimum elevation angle for the satellites (elevation mask).*
- *Positional Dilution of Precision (PDOP) or Geometric Dilution of Precision (GDOP).*
- *Vertical Dilution of Precision (VDOP).*

***Field Procedures**: Proper field procedures shall be followed in order to produce an effective RTK survey.*

***For Third-order RTK Surveys, these procedures shall include**:*

- *It is recommended that the base station occupy an RTK control station with known coordinates for horizontal RTK surveys and known heights for vertical RTK surveys.*
- *A fixed height tripod shall be used for the base station.*
- *A fixed height survey rod or a survey rod with locking pins shall be used for the rover pole. A tripod and a tribrach may also be used. If a fixed height survey rod or a survey rod with locking pins is not used, independent antenna height measurements are required at the beginning and ending of each setup and shall be made in both feet and meters. The antenna height measurements shall check to within ± 3mm and ± 0.01 feet.*
- *A bipod/tripod shall be used with the rover unit's survey rod.*
- *The data transfer link shall be established.*
- *A minimum of five common satellites shall be observed by the base station and the rover unit(s).*
- *The rover unit(s) shall be initialized before collecting survey data.*
- *The initialization shall be a valid checked initialization.*
- *PDOP shall not exceed 5.*
- *Data shall be collected only when the root mean square (RMS) is less than 70 millicycles.*
- *A check shot shall be observed by the rover unit(s) immediately after the base station is set up and before the base station is taken down.*
- *The GPS site calibration shall have a maximum horizontal residual of 20 mm for each horizontal RTK control station.*
- *The GPS site calibration shall have a maximum vertical residual of 30 mm for each vertical RTK control station.*
- *The new stations shall be occupied for a minimum of 30 epochs of collected data.*
- *The precision of the measurement data shall have a value less than or equal to 10 mm horizontal and 15 mm vertical for each observed station.*
- *The rover unit(s) shall not be more than 10 km from the base station.*
- *The 2nd occupation of a new station shall have a maximum difference in coordinates from the 1st occupation of 20 mm.*
- *The 2nd occupation of a new station shall have a maximum difference in height from the 1st occupation of 40 mm.*
- *When setting supplemental control by RTK methods for conventional surveys methods, it is recommended that the new control points be a minimum of 300 meters from each other.*
- *When establishing set-up points for conventional survey methods, set three intervisible points instead of just an "azimuth pair." This allows the conventional surveyor a check shot.)*

For general-order RTK surveys, these procedures shall include:

- *It is recommended that the base station occupy an RTK control station with known coordinates for horizontal RTK surveys and known heights for vertical RTK surveys.*
- *Fixed height tripods are recommended for the base station. If fixed height tripods are not used, independent antenna height measurements are required at the beginning and ending of each setup and shall be made in both feet and meters. The antenna height measurements shall check to within ± 3 mm and ± 0.01 feet.*
- *A fixed height survey rod or a survey rod with locking pins shall be used for the rover poles. A tripod and tribrach may also be used. If a fixed height survey rod or a survey rod with locking*

pins is not used, independent antenna height measurements are required at the beginning and ending of each setup and shall be made in both feet and meters. The antenna height measurements shall check to within ± 3 mm and ± 0.01 feet.

- *A bipod/tripod shall be used with the rover unit's survey rod.*
- *The data transfer link shall be established.*
- *A minimum of five common satellites shall be observed by the base station and the rover unit(s).*
- *The rover unit(s) shall be initialized before collecting survey data.*
- *The initialization shall be a valid checked initialization.*
- *PDOP shall not exceed 6.*
- *Data shall be collected only when the root mean square (RMS) is less than 70 millicycles.*
- *A check shot shall be observed by the rover unit(s) immediately after the base station is set up and before the base station is taken down.*
- *The GPS site calibration shall have a maximum horizontal residual of 20 mm for each horizontal RTK control station.*
- *The GPS site calibration shall have a maximum vertical residual of 30 mm for each vertical RTK control station.*
- *The precision of the measurement data shall have a value less than or equal to 15 mm horizontal and 20 mm vertical for each observed station.*
- *The rover unit(s) shall not be more than 10 km from the base station.*

Office Procedures*: Proper office procedures must be followed in order to produce valid results. These procedures shall include:*

- *Review the downloaded field file for correctness and completeness.*
- *Check the antenna heights for correctness.*
- *Check the base station coordinates for correctness.*
- *Analyze all reports.*
- *Compare the different observations of the same stations to check for discrepancies.*
- *After all discrepancies are addressed, merge the observations.*
- *Analyze the final coordinates and the residuals for acceptance.*

General Notes:

- *At present, RTK surveys shall not be used for pavement elevation surveys or for staking major structures.*
- *If the data transfer link is unable to be established, the RTK survey may be performed with the intent of post processing the survey data.*
- *The data transfer link shall not "step on" any voice transmissions.*
- *If a UHF/VHF frequency is used for the data transfer link, it shall be checked for voice transmissions before use.*
- *The data transfer link shall employ a method for ensuring that the signal does not interfere with voice transmissions.*
